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A Study on Simple Beam Bridge Responses Due to Thai Truck Loads

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Abstract

Thai truck weight limits rated by the Department of Highways (DOH) are different from the vehicular design loadings specified by American or European bridge design codes, which are usually referred to as international standards. For the bridge design practice in Thailand, engineers have to calibrate the design live loads obtained from these international standards with the existing Thai truck weight limits in order to achieve the same level of bridge safety. This article comparatively studied the load-carrying behavior of simple beam bridges with the span length ranging from 5 to 60 meters due to Thai truck loads against the AASHTO(STD&LRFD) and EN1991-2 design live loads defined by the American and European standards, respectively. The objective of this study was to compare the maximum shear and bending moment of the simple beam bridges due to various types of loadings. The proper ratios of the shear, also bending moment, between the AASHTO(STD&LRFD) and EN1991-2 loads against Thai truck loads were proposed. The results showed that, in each span, the maximum shear and bending moment were caused by various types of trucks. Additionally, the heaviest truck produced the maximum responses for some analysis cases. From the comparative analysis, the shear ratios and the moment ratios were proposed associated with various bridge span lengths. For bridge design practice in Thailand, these ratios could be applied as multipliers to the AASHTO(STD&LRFD) or EN1991-2 loads; therefore, the bridge responses were conformable to those of Thai truck loads.

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Keywords: Thai Trucks, Shear Ratios, Moment Ratios, Bridge Design

1. Introduction

A bridge structure is used for supporting vehicles to cross over the obstacles on route. For bridge design practice in Thailand, the provisional standard specifications specified by AASHTO (American Association of State Highway and Transportation Officials), AASHTO(STD), [1] have usually been referred. Thai engineers

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must concern the variety of vehicles defined in the government gazettes and declarations issued by the Department of Highways (DOH) [2-7]. Besides, the government-specified vehicles, especially for trucks so called Thai trucks, differ from AASHTO(STD) design loadings designated as HS20-44. It should be noted that AASHTO(STD) allows to proportionally adjust the designated loadings in case the design vehicles are different from the code-specified vehicles [1]. Additionally, the standard vehicular design loadings, not only in the United States, were individually developed in most countries around the world since the vehicle characteristics and usages of traffic on bridges were supposed to be dissimilar. The most interesting one is those from the European Communities. Nevertheless, Thai trucks still differ from those mentioned loadings. In order to achieve the conformable bridge responses determined from Thai trucks and other code-specified design loadings, the engineers should intentionally multiply the design live loads by a correction factor in the design process.

It should be stated that, for particular bridge spans or specific types of trucks, bridge responses calculated from HS20-44 were shown in insufficient of bridge safety on when the real truck had been moving. For some specific area, the design vehicles should be calibrated with the standard live loadings in order to reflect the realistic behavior of the bridges [8,9]. In Thailand, Sritanet et al. [10] studied the safety of girder-type bridges by comparing the bridge responses due to 7 convoys of Thai trucks according to the declarations of DOH with HS20-44. The analytical results showed that the stresses in bridge girders due to 38-ton semi-trailer and 35-ton trailer were approximately 26% and 23% greater than those calculated from HS20-44, respectively. However, this research was limited the span length of the bridge only to 37.16 m. Vivithkeyoonwong et al. [11] evaluated the stresses in the bridge girders due to Thai trucks with the total weight of 21, 26, 28 and 35 tons compared with those from HS20-44. The span lengths ranged from 10 to 38 m. The analysis showed that, for short bridges with span length not exceeding 15 m., HS20-44 can safely be used instead of 21-ton Thai trucks, while, at span length of 38 m., the absolute maximum moments were approximately 94.7% greater than those from HS20-44. Especially, for 28- and 35-ton trucks, the maximum stresses would be highly produced in the amount of 170.5% and 238.3% greater than those from HS20-44, respectively.

Subsequently, Suparp et al. [12,13] investigated the bridge responses of simple beam system with several span lengths ranging from 5-60 m. due to HS20-44 and Thai trucks. Likewise, the bridge responses of continuous beam system with the total length of the bridges ranging from 90 m. to 180 m. were also studied [14,15]. The researches aimed to compare the maximum shear and bending moment due to HS20-44 with Thai trucks according to the government gazettes issued by the DOH from 2005 to 2009 [2-7]. From the analytical results, the bridge response ratios were comparatively proposed associated with the span lengths of the bridges. These ratios could be applied as multipliers to HS20-44; therefore, the bridge responses were conformable to those of Thai truck loads. It should be noted that the research es mentioned above was basically investigated on AASHTO(STD). Afterward, the bridge responses between Thai trucks and HL-93, specified by AASHTO(LRFD) [16], had continuously been being studied by Suparp et al. [17]. On those studies, however, the dynamic effects of Thai trucks and AASHTO live loadings were assumed to be equal. Moreover, the vehicle effects on bridges were analyzed and loaded in one lane. It can be seen that the comparisons of vehicular bridge live loadings are still focused on those specified by the United States. Nevertheless, it can be presumed that the comparative studies of bridge responses mentioned above have been carried out with continuously extensive applications.

Thus, this paper aimed to quantitatively compare the responses of simple beam bridges due to Thai truck loadings with the American and European standard live loadings. Additionally, the maximum ratios of bridge responses, shear and bending moment, due to American and European loadings were compared with those from Thai trucks. The dynamic impact effects and reduction in load intensity due to improbable coincident of simultaneous loaded lanes were separately incorporated in the analysis for each standard. For bridge design practice in Thailand, these ratios could be applied as multiplier to those standard loadings; hence, the maximum shear and bending moment of simple beam bridge caused by those proportioned standard loadings and Thai truck are comparable. In addition, the results of this study would be employed as the basic data for further development of standard loadings for bridge design in Thailand.

2. Highway Live Loadings for Bridge Design

2.1 Loadings of Thailand

Referred to the government gazettes issued in 2005 by DOH [2], Thai trucks were rated by weight limits and composed of three types of vehicles typically defined as (1) a single unit or truck (2) a truck with semi-trailer and (3) a truck with full trailer as shown in Figure 1. After that, the DOH had issued the additional declarations [3-7] containing special trucks or vehicles for overloaded transportation, proper axle and gross weights of each type of vehicles. Besides, the distances between king pin of truck to the first axle of semi-trailer (S in Figure 1) were relatively varied to the axle loads. In this study, however, several types of those vehicles, particularly used in normal traffic, were selected with three criteria as followed; (1) if vehicle configurations were similar, the heaviest vehicles were selected (2) if vehicle weights were equal, the vehicles with closer axle distances were selected and (3) the types of vehicles which will be revoked by 31 December 2012 are necessarily not to be considered. As the criteria stated above, only 2 types of trucks, 9 types of trucks with semi-trailer and 4 types of trucks with full-trailer were taken into account for the analysis [12] as shown in Table 1. It should be noted that despite of not having the axle distances in the declarations, the axle distances were gathered from many truck manufacturers [13].

Due to not having the standard loadings for bridge design in Thailand, Thai trucks were successively arranged into a convoy of truck which was similar to the truck train loading pattern specified in AASHTO(STD) [1: Appendix B]. The distances between the rear axle of the front vehicle and the front axle of the successive one were traditionally defined as 9.14 m. (30 ft.). The trains of trucks were composed of the truck and the same type of trucks with 25% reduction of their own weight as shown in Figure 2. The maximum responses from every convoy of Thai truck were presented as the enveloping values. The analysis included the dynamic impact effects specified by AASHTO(STD) per the formula given as 15.24/(L+38) [1] ; when L is a bridge span length in meters.

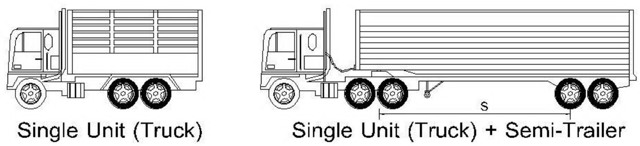


Fig. 1. Typical Vehicles of Thai Trucks

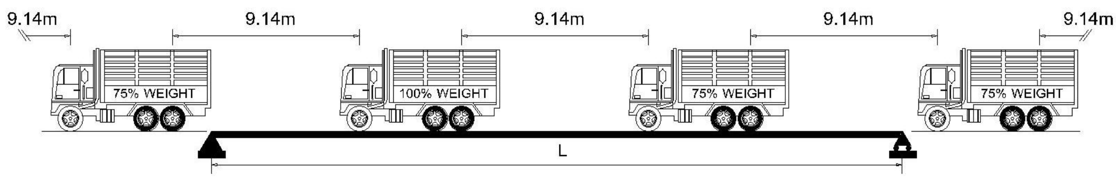
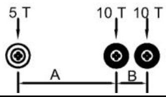
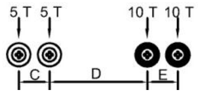
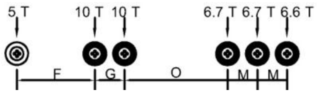
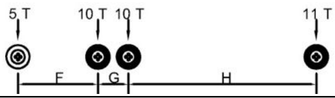
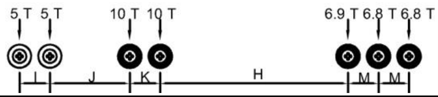
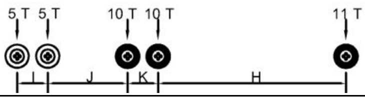
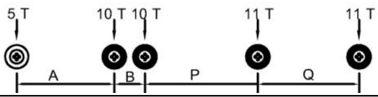
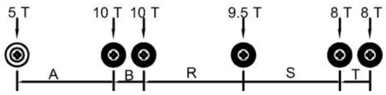
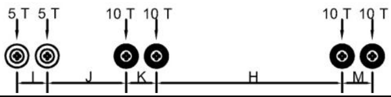
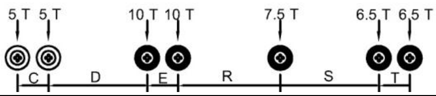
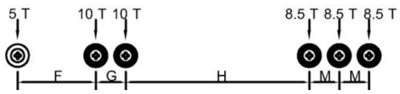
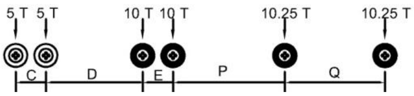


Fig. 2. Truck Train Loadings for Thai Trucks

Table 1. Thai Truck Loadings

Truck Types *(Total Weight : tons)*	**Axle Loads**	**Truck Types** *(Total Weight : tons)*	**Axle Loads**
Truck25 *(25)*		Semi47 *(47)*	
Truck30 *(30)*		Semi45(2) *(45)*	
Semi36 *(36)*		Semi50.5(2) *(50.5)*	
Semi41 *(41)*		Full47 *(47)*	
Semi45(1) *(45)*		Full50.5(1) *(50.5)*	
Semi50 *(50)*		Full50.5(2) *(50.5)*	
Semi50.5(1) *(50.5)*		Full50.5(3) *(50.5)*	
Semi49 *(49)*			

Remarks : The nomenclatures of axle distances are tabulated below;

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
4025	1250	1300	3300	1250	3025	1250	6825	1300	3025	1250	5825	1250	4825	3325	4775	4300	3325	4025	1250

2.2 Loadings of the United States of America

2.2.1 Loadings of AASHTO(STD)

The AASHTO standard specifications, AASHTO(STD), stipulates four classes of truck loadings and equivalent lane loadings; H20, H15, HS20 and HS15. The weights of loading H15 and H20 are 75% of HS15 and HS20, respectively. The heaviest loadings are designated as HS20-44 comprising of a tractor truck with a semi-trailer or a corresponding lane loading as shown in Table 2. The dynamic effects are to be added in both cases of loading by the formula given as 15.24/(L+38) where L is the span length in meters. The standard truck or lane loadings shall be assumed to occupy a width of 3.00 m. In view of improbable coincident loadings, the probability of the maximum stresses occur in any member by loading any number of traffic lanes simultaneously, the reduction in load intensity shall be applied as 90% and 75% of the resultant live loads for three lanes and more than three lanes, respectively. There is, however, no reduction intensity for up to two lanes of traffic loaded.

2.2.2 Loadings of AASHTO(LRFD)

The AASHTO developed the new bridge standard loading called HL-93 (Highway Loading, developed in 1993). This model consists of three distinctive different live loads; i.e., (1) design truck (2) design tandem and (3) design lane as shown in Table 2. HL-93(Tandem) represents the combination of distinctive live loads of design tandem and the design lane load. Likewise, HL-93(Truck) represents the combination loads of design truck and the design lane load. HL-93(Continuous) represents the bridge live loads consisting of two design truck loads and design lane load, all scaled by 90%. For continuous beam systems, HL-93(Continuous) is only used for negative superstructure moments over supports and reactions at interior supports. For typical structural components in the limit states other than fatigue and fracture, a dynamic load allowance may be presented as the additive percentage of 33% directly added to all concentrated axle loads but the uniform lane load is not affected. The HL-93 live loads also occupy a width of 3.00 m. as indicated in AASHTO(STD). The extreme live loads shall be determined by multiplying with the multiple presence factors which are taken into account for the improbable coincident loadings. These factors are 1.2, 1.0, 0.85 and 0.65 for the number of loaded lane of 1, 2, 3 and greater than 3, respectively.

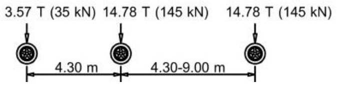
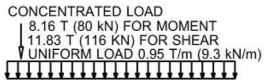
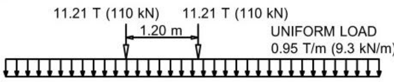
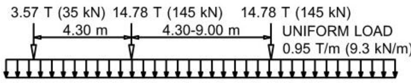
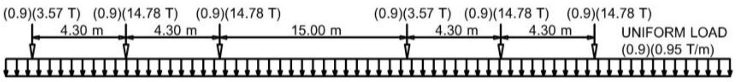
2.3 Loadings of the Eurocodes (EN1991-2)

The Eurocodes were developed as provisional standards under the responsibility of the Commission of European Communities. The Structural Eurocodes program comprises of many standards; i.e., Eurocodes, Eurocodes 1 to 9, had been developed in series since 1990. EN1991-2 [18] is one of them involving the traffic loads on bridges. Four model of vertical loads denoted LM1 to LM4 are defined for serviceability and ultimate limit state verification except fatigue verification. However, the main characteristic load model LM1, comprising of tandem system of two concentrated loads and uniformly distributed load as shown in Figure 3, is applicable to all bridges. The characteristic values of tandem system and uniformly distributed loads on lane No. i are denoted as $\alpha_{Qi}Q_{ik}$ and $\alpha_{qi}q_{ik}$, respectively. The adjustment factors, α_{Qi} and α_{qi} , are taken into account for various types of traffic on bridges. For first class road bridges, these values are generally equal to 1.0 [19]. The characteristic values of the loads for LM1 are given in Table 3. It can be seen that, for greater than three loaded lanes, the tandem system loads are neglected, but the uniformly distributed load shall be remained with 2.5 kN/m^2. Both of two loadings occupy a width of 3.00 m. for each lane. The dynamic effects are already included in the characteristic values of loadings.

3. Structural Analysis and Modeling

For quantitative comparisons, the maximum shear and bending moment were determined. Bridge standard loadings for each code were separately implemented on the bridge, including the dynamic effect and the improbable coincident loadings. The analytical span lengths were ranged from 5 to 60 m. which could likely cover the great majority of simple beam bridges. The influence-based enveloping method was used to analyze the minimum or maximum responses due to moving vehicles. The worst effects of shear and bending moment calculated from each code shall be added with a dynamic impact factor of its own code-specified formula. In addition, the factors representing the improbable coincident loadings were also separately considered according to each standard.

Table 2. AASHTO Loadings

Truck Types ***(Total Weight : tons)***	**Loading Characteristics**	**Remarks**
HS20-44(Truck) *(33.13)*		1. HS20-44 is the bridge standard loadings specified by AASHTO (STD) 2. HL-93 is the bridge standard loadings specified by AASHTO (LRFD) 3. L is bridge span length.
HS20-44(UCL) *(0.95L+8.16 or 11.83)*		
HL-93(Tandem) *(0.95L+22.42)*		
HL-93(Truck) *(0.95L+33.13)*		
HL-93(Continuous) *(0.86L+59.63)*		

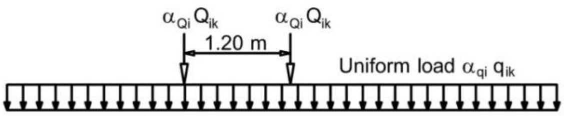


Fig. 3. Load Model No. 1 (LM1) for EN1991-2 [18]

Table 3. Characteristic Values of Loadings for Load Model No. 1

Location	**Tandem System of Axle Loads,** Q_{ik} (kN)	**Uniformly Distributed Loads,** q_{ik} (kN/m^2)
Lane No. 1	300	9
Lane No. 2	200	2.5
Lane No. 3	100	2.5
Other Lanes	0	2.5
Remaining Area (q_{rk})	0	2.5

4. Results and Discussions

From the point of view of qualitative comparisons from the summarized data, it was found that, with the exception of Thai loadings, three major codes have both uniformly distributed loadings and, at least, alternate truck or tandem loadings. Because there is no bridge standard loading in Thailand, truck train loadings are comparatively considered as the design live load. For AASHTO(STD&LRFD) and EN1991-2, the floating concentrated loads in combination with uniformly distributed load are specified. However, the concentrated loads specified by AASHTO(STD) have different values for calculating shear and bending moment. It could be observed that the equivalent of uniformly distributed loading system seems to be popularly used because of its simplicity for applications. Concerning the improbable coincident loadings, the load intensities of HS20-44 are proportionally factored by 1.0 for up to two loaded lanes. HL-93 loadings, whereas, are factored by 1.2 and 1.0 for one and two loaded lanes, respectively. Furthermore, the characteristic values for LM1 are different for various loaded lanes. It should also be expressed that, in AASHTO(STD), an impact factor is correlated with a span length but that of AASHTO(LRFD) is specified as the constant value of 33%. However, the dynamic effect for LM1 is already included. It can be seen that the live load models, dynamic effects and improbable coincident loadings are remarkably different depending on the traffic characteristics and behaviors of each country. With the aim of comparative study for bridge responses due to live loads, these three parameters shall be considered simultaneously.

For quantitative comparisons, the values of maximum shear and bending moment including impact for one and two loaded lanes were determined as shown in Table 4 to Table 7. The values which were greater than those of Thai loadings were shaded. It can be seen that the bridge responses from the loadings other than HS20-44 were mostly greater than those from Thai Loadings. It should be revealed that Semi45(2) produced the maximum shears and the maximum moments for spans greater than 30 m., and greater than 40 m, respectively. Otherwise, for span of 5, 10, 15, 20, and 25 m., the maximum shears were caused by Semi.50.5(1), Semi45(2), Full50.5(1), Semi50.5(1) and Semi49, respectively. Likewise, for a span of 5 and 10, 15 and 20, 25 and 30, and 35 m., the maximum moments were caused by Semi50.5(1), Semi45(2), Full50.5(2) and Full47, respectively. It can be seen that the maximum responses were not necessarily caused by the heaviest trucks.

It appears better to comparatively observe the bridge responses by using a ratio which is the proportion of a response due to each code-specified loadings against a response due to Thai loadings. Hence, the ratios of shear and bending moment, for both one and two loaded lanes, were determined and plotted against the span lengths as shown in Figure 4 to Figure 7. It can be seen that the bridge responses due to LM1 were the largest for one and two loaded lanes while the responses due to HS20-44 provided the minimum effects. In a point of view of improbable coincident loadings for up to two lanes, the responses due to HS20-44 for two loaded lanes were twice of those for one loaded lane but the responses from HL-93 were only 1.67, whereas those from LM1 were varied from 1.44 to 1.62 (average value: ~1.51). It also seems that the maximum response ratios were obviously found at the span lengths of approximately 5 to 10 m. and 25 to 35 m. The ratios, however, tended to be decreased when the larger spans were considered. In addition, the ratios can be applied as multiplier to the HS20-44, HL-93 and LM1 loadings,; consequently, the bridge responses may be conformable to those from Thai truck loads.

Table 4. Maximum Shear for One Loaded Lane

Span (m)	Maximum Shear (kN)			
	Loadings of Thailand	HS20-44 Loadings	HL-93 Loadings	LM1 Loadings
0	0	0	0	0
5	244	215	337	595
10	346	302	427	699
15	403	339	504	778
20	440	352	556	852
25	482	358	599	923
30	542	360	637	993
35	592	361	672	1062
40	631	361	705	1131
45	669	385	737	1199
50	719	409	768	1268
55	761	433	799	1336
60	802	456	829	1404

Table 5. Maximum Moment for One Loaded Lane

Span (m)	Maximum Moment (kN-m)			
	Loadings of Thailad	HS20-44 Loadings	HL-93 Loadings	LM1 Loadings
0	0	0	0	0
5	271	236	371	657
10	678	581	912	1659
15	1339	1070	1641	2829
20	2011	1563	2534	4170
25	2667	2041	3496	5679
30	3387	2509	4528	7357
35	4237	2969	5630	9204
40	5292	3422	6801	11220
45	6565	3868	8029	13356
50	7979	4566	9341	15713
55	9522	5357	10723	18237
60	11053	6221	12185	20970

Table 6. Maximum Shear for Two Loaded Lanes

Span (m)	Maximum Shear (kN)			
	Loadings of Thailand	HS20-44 Loadings	HL-93 Loadings	LM1 Loadings
0	0	0	0	0
5	488	430	561	966
10	691	605	711	1112
15	806	678	840	1219
20	880	704	927	1315
25	963	715	999	1407
30	1084	720	1061	1497
35	1184	722	1120	1587
40	1263	722	1175	1675
45	1337	770	1228	1763
50	1439	818	1280	1850
55	1521	865	1331	1938
60	1604	913	1381	2025

Table 7. Maximum Moment for Two Loaded Lanes

Span (m)	Maximum Moment (kN-m)			
	Loadings of Thailand	HS20-44 Loadings	HL-93 Loadings	LM1 Loadings
0	0	0	0	0
5	542	471	618	1064
10	1355	1162	1520	2633
15	2679	2141	2736	4420
20	4023	3125	4223	6425
25	5334	4083	5827	8645
30	6774	5019	7547	11081
35	8473	5938	9383	13732
40	10584	6843	11336	16600
45	13130	7736	13382	19614
50	15957	9132	15569	22918
55	19044	10714	17871	26436
60	22105	12443	20308	30224

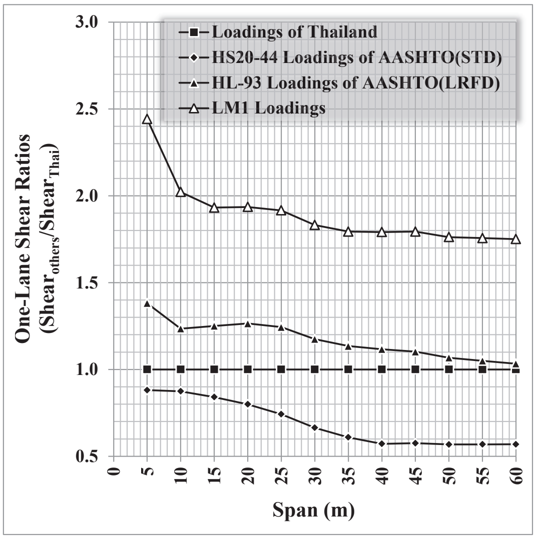


Fig. 4. Maximum Shear Ratios from American and European loadings and Thai Loadings (One Loaded Lane)

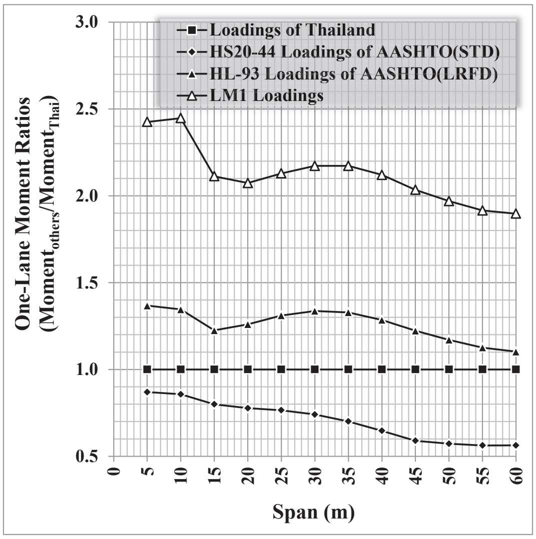


Fig. 5. Maximum Moment Ratios from American and European loadings and Thai Loadings (One Loaded Lane)

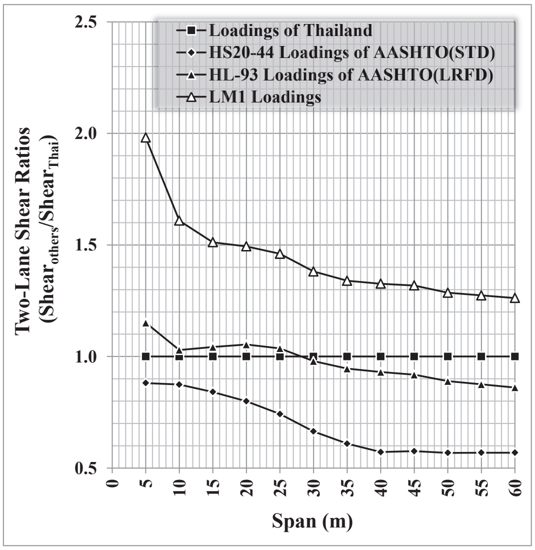


Fig. 6. Maximum Shear Ratios from American and European loadings and Thai Loadings (Two Loaded Lanes)

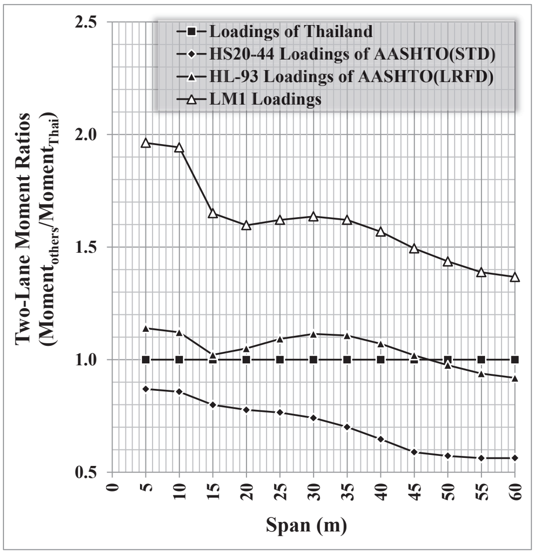


Fig. 7. Maximum Moment Ratios from American and European loadings and Thai Loadings (Two Loaded Lanes)

5. Conclusions

This paper studied the quantitative comparisons of bridge responses due to loadings of Thailand and three codes from two standards; i.e., American and European standards. All vehicle types in Thailand were referred to the declarations from several government gazettes mainly issued by DOH. The characteristic variations of bridge standard loadings were also qualitatively examined. The main founding was that, with the exclusion of Thai loadings, two standards have both uniformly distributed loads with floating concentrated loads and at least alternate truck loads. The improbable coincident loading was to be considered by a given value multiplied to the bridge responses. Concerning the dynamic effects of bridges, the impact factors shall be added up to the bridge responses by the given formula for each country. For quantitative comparisons, bridge responses for span length of 5 m. to 60 m. were analyzed and represented as shears and bending moments, including impact, for one and two loaded lanes. It was shown that the bridge responses of Thai loadings were less than those of various codes except HS20-44. Additionally, the ratios of bridge responses due to loadings from other codes compared with those from Thailand were also plotted against the span lengths. It can be seen that, when the longer spans were considered, the maximum ratios were seemingly decreased. Because of the differences in bridge standard loadings, the comparisons of vehicular loadings would necessarily be more conducted in order to achieve basic data for further development of bridge standard loadings in Thailand.

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